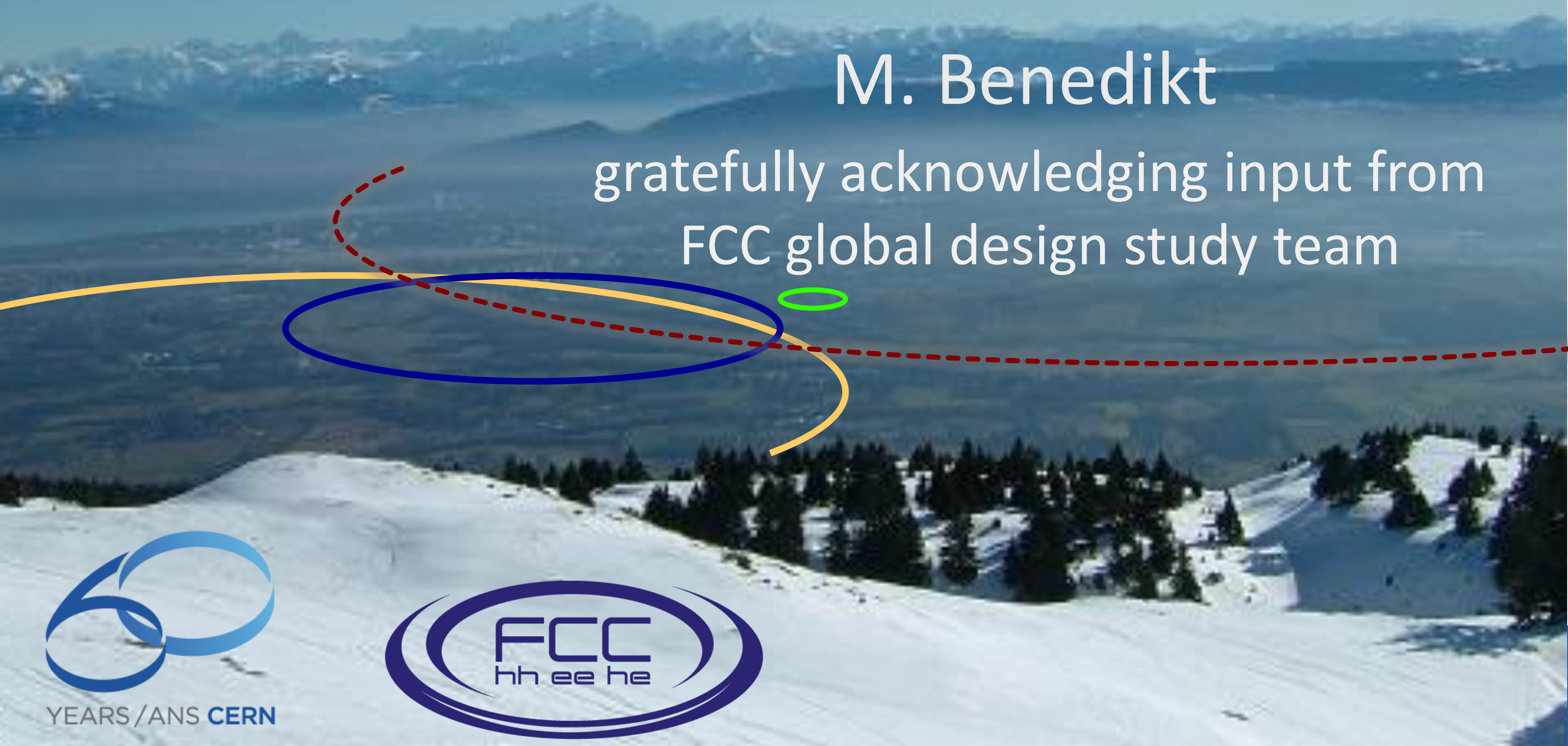
Future Facilities: motivations and challenges

High-Energy Proton Colliders



M. Benedikt

gratefully acknowledging input from
FCC global design study team

Outline

- Motivations
- High-energy proton colliders
- Parameters & challenges
- FCC study status

Hadron collider motivation: pushing the energy frontier

- A very large circular hadron collider seems **the only approach to reach 100 TeV c.m. range** in coming decades
- Access to **new particles (direct production) in the few TeV to 30 TeV mass range**, far beyond LHC reach.
- **Much-increased rates for phenomena in the sub-TeV mass range** →increased precision w.r.t. LHC and possibly ILC

M. Mangano

The name of the game of a hadron collider is energy reach

$$\boxed{E \propto B_{dipole} \times \rho_{bending}}$$

Cf. LHC: factor ~4 in radius, factor ~2 in field → O(10) in E_{cms}

Strategic Motivation

- **European Strategy for Particle Physics 2013:**

  "…to propose an ambitious post-LHC accelerator project….., CERN should undertake design studies for accelerator projects in a global context,…with emphasis on proton-proton and electron-positron high-energy frontier machines.…."

- **ICFA statement 2014:**

  ".… ICFA supports studies of energy frontier circular colliders and encourages global coordination.…."

- **US P5 recommendation 2014:**

  ".…A very high-energy proton-proton collider is the most powerful tool for direct discovery of new particles and interactions under any scenario of physics results that can be acquired in the P5 time window…."

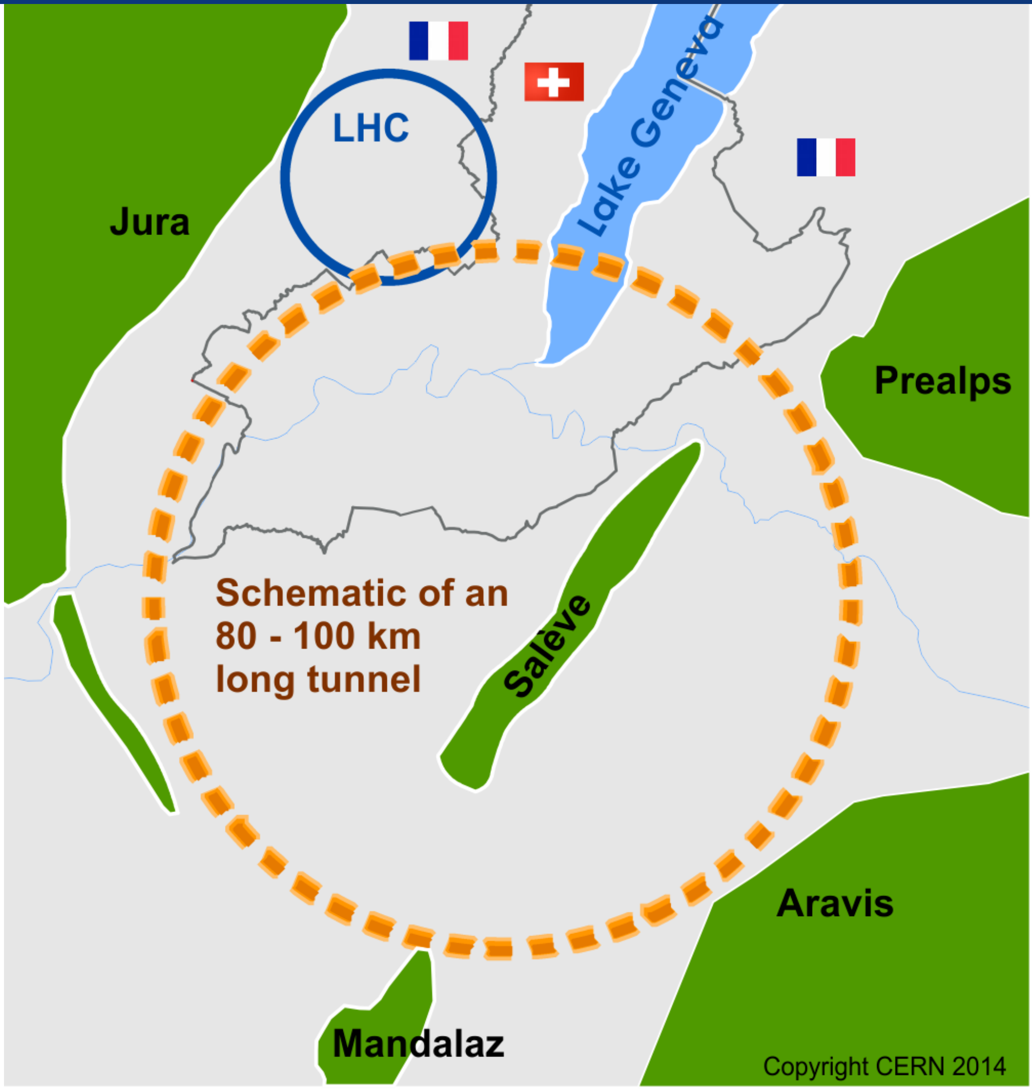
Future Circular Collider Study
GOAL: CDR and cost review for the next ESU (2018)

International FCC collaboration to study:

- ***pp*-collider (*FCC-hh*)** → main emphasis, defining infrastructure

~16 T ⇒ 100 TeV *pp* in 100 km
~20 T ⇒ 100 TeV *pp* in 80 km

- **80-100 km infrastructure** in Geneva area
- **e^+e^- collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (FCC-he) option**



Copyright CERN 2014

CepC/SppC study (CAS-IHEP) 50-70 km

e^+e^- collisions ~2028; *pp* collisions ~2042

- easy access
- 300 km from Beijing
- 3 h by car
- 1 h by train

"Chinese Toscana"

Image © 2013 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2013 Mapabc.com
Image © 2013 TerraMetrics
Google earth

Yifang Wang

Previous studies in Italy (ELOISATRON 300km), USA (SSC 87km, VLHC 233km), Japan (TRISTAN-II 94km)

ex. ELOISATRON

Supercolliders Superdetectors: Proceedings of the 19th and 25th Workshops of the INFN Eloisatron Project

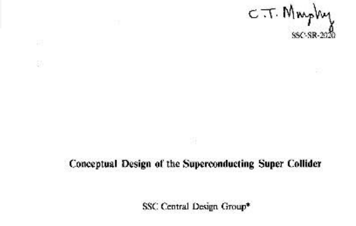

THE SCIENCE AND CULTURE SERIES — PHYSICS

SUPERCOLLIDERS AND SUPERDETECTORS

Editors W. A. Bar

World S

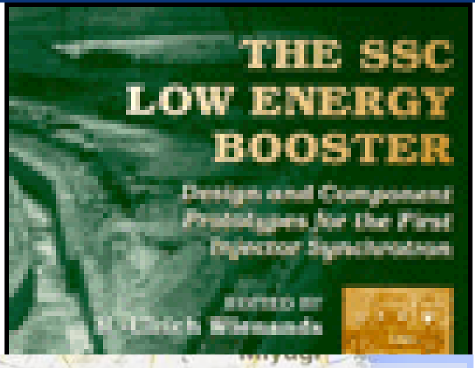
ex. SSC


C.T. Murphy

SSC-SR-2020

Conceptual Design of the Superconducting Super Collider

SSC Central Design Group*


THE SSC LOW ENERGY BOOSTER

Design and Component Prototypes for the First Injector Synchrotron

EDITED BY Ulrich Wienands

SSC C

ex. TRISTAN II

Tristan-II option 2

Tristan-II option 1

F. Takasaki

Many aspects of machine design and R&D non-site specific.

→ Exploit synergies with other projects and prev. studies

ex. VLHC

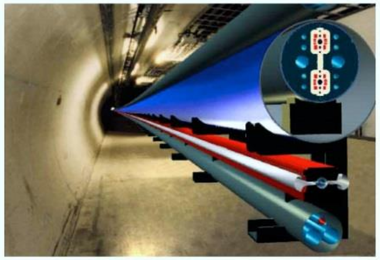
VLHC Design Study Group Collaboration
June 2001. 271 pp.
SLAC-R-591, SLAC-R-0591, SLAC-591, SLAC-0591, FERMILAB-TM-2149

Very Large Hadron Collider

Fermilab-TM-2149
June 4, 2001

Design Study for a Staged Very Large Hadron Collider

The VLHC Design Study Group:
Brookhaven National Laboratory
Fermi National Accelerator Laboratory
Laboratory of Nuclear Studies, Cornell University
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center



http://www.vlhc.org/

Key challenges for hadron colliders

- **High energy**
  - ⇒ High field superconducting magnets
  - ⇒ Large tunnel infrastructures

- **High luminosity**
  - ⇒ Beam optics
  - ⇒ Beam current
  - ⇒ Synchrotron radiation to SC magnets
  - ⇒ IR shielding and element lifetime

- **High stored beam energy**
  - ⇒ Machine protection
  - ⇒ Beam handling
  - ⇒ Beam injection and dumping

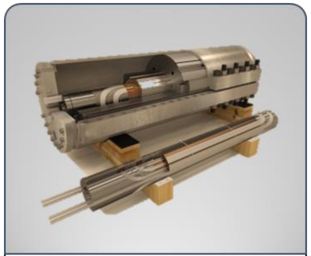
FCC Scope: Accelerator and Infrastructure

Collider Designs

FCC-hh: **100 TeV pp collider as long-term goal**
→ defines infrastructure needs

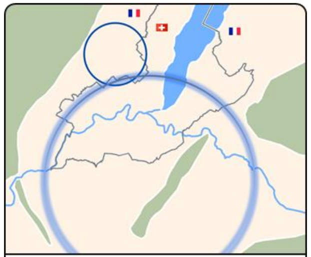
FCC-ee: **e$^+$e$^-$ collider**, potential intermediate step

FCC-he: **integration aspects** of pe collisions



R&D Programs

Push key technologies
in dedicated R&D programmes e.g.
16 Tesla magnets for **100 TeV** pp in **100 km**
SRF technologies and RF power sources

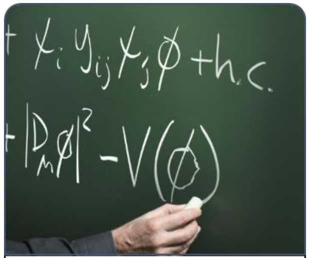


Infrastructures

Tunnel infrastructure in Geneva area, linked to CERN accelerator complex

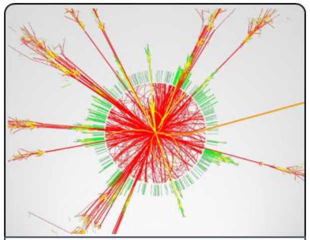
Site-specific, requested by European strategy

Scope: Physics & Experiments



Physics Cases

Elaborate and document
- Physics opportunities
- Discovery potentials



Experiments

Experiment concepts for hh, ee and he
Machine Detector Interface studies
Concepts for worldwide data services

Cost Estimates

Overall cost model
Cost scenarios for collider options
Including infrastructure and injectors
Implementation and governance models

FCC-hh parameters

parameter	**FCC-hh**		LHC	HL LHC
energy cms [TeV]	**100**		14	
dipole field [T]	**16**		8.3	
# IP	**2 main & 2**		2 main & 2	
bunch intensity [10^{11}]	**1**	**1 (0.2)**	1.1	2.2
bunch spacing [ns]	**25**	**25 (5)**	25	25
luminosity/Ip [10^{34} cm^{-2}s^{-1}]	**5**	**20**	1	5
events/bx	**170**	**680 (136)**	27	135
stored energy/beam [GJ]	**8.4**		0.36	0.7
synchr. rad. [W/m/apert.]	**30**		0.2	0.35

FCC-hh preliminary layout

100 km layout for FCC-hh (different sizes under investigation)

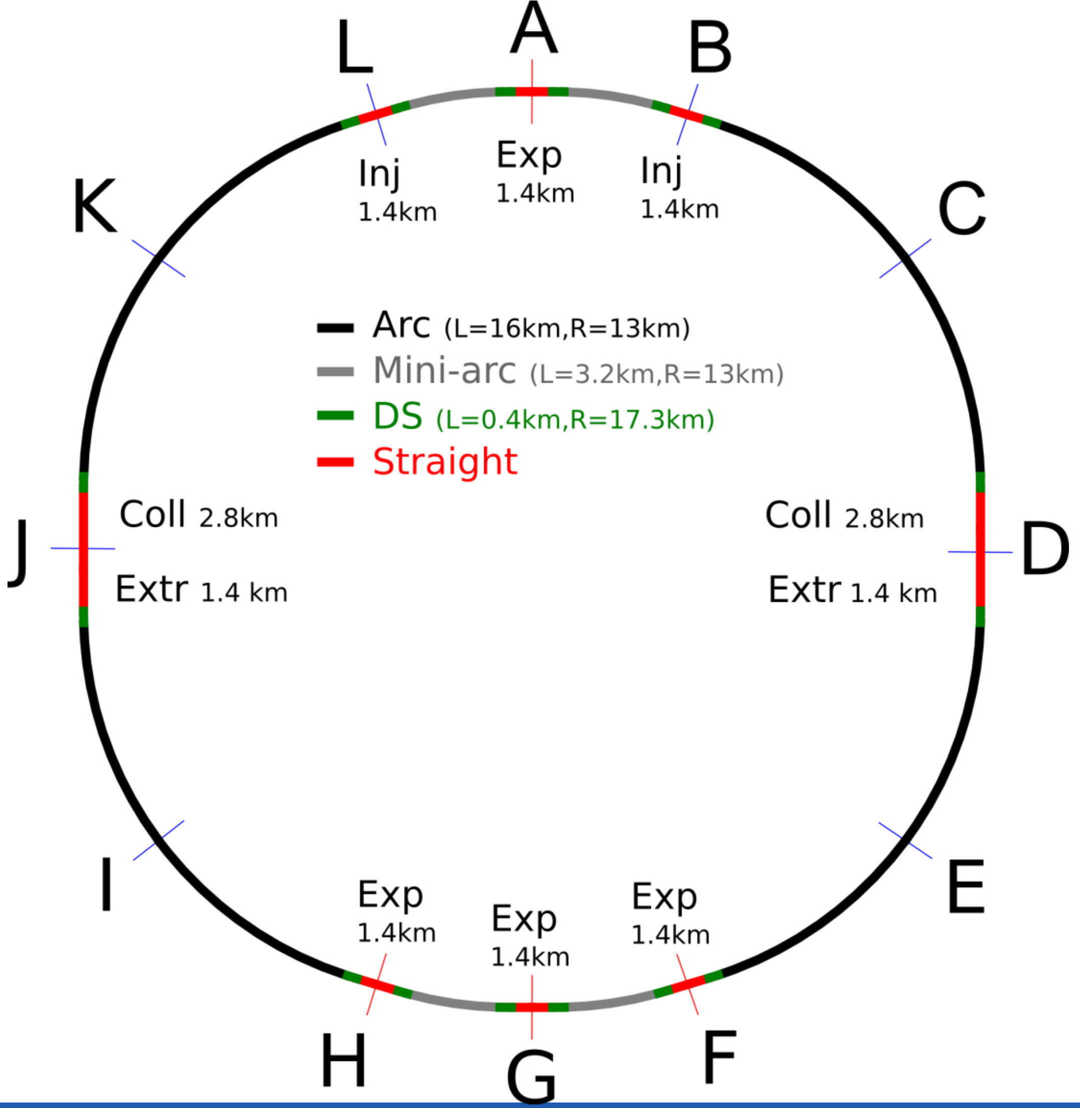
⇒ Two high-luminosity experiments (A and G)

⇒ Two other experiments (F and H)

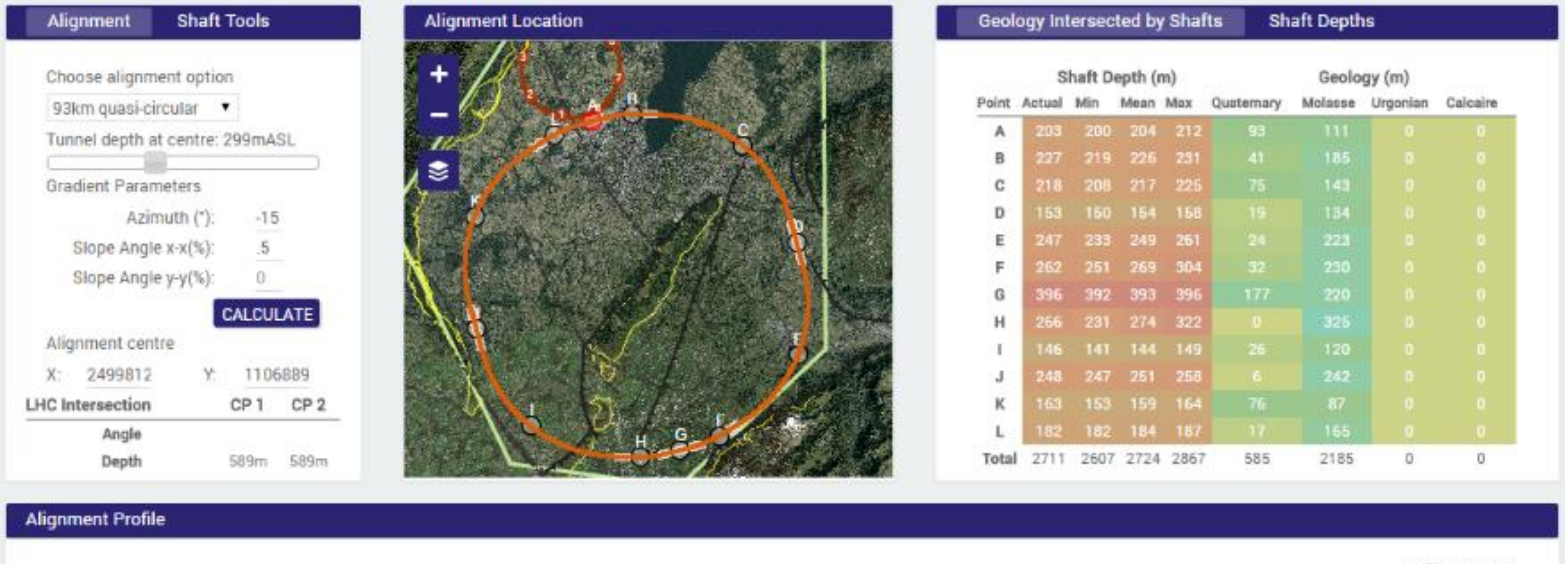
⇒ Two collimation lines

⇒ Two injection and two extraction lines

Orthogonal functions for each insertion section



Site study 93 km example



Choose alignment option: 93km quasi-circular

Tunnel depth at centre: 299mASL

Gradient Parameters

Azimuth (°): -15

Slope Angle x-x(%): .5

Slope Angle y-y(%): 0

Alignment centre

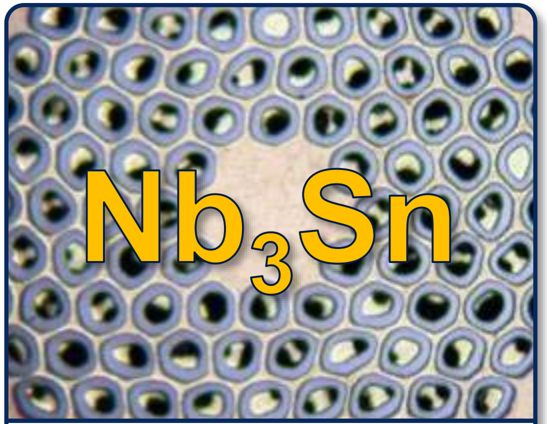
X: 2499812 Y: 1106889

LHC Intersection	**CP 1**	**CP 2**
Angle		
Depth	589m	589m

	Shaft Depth (m)				Geology (m)			
Point	Actual	Min	Mean	Max	Quaternary	Molasse	Urgonian	Calcaire
A	203	200	204	212	93	111	0	0
B	227	219	226	231	41	185	0	0
C	218	208	217	225	75	143	0	0
D	153	150	154	158	19	134	0	0
E	247	233	249	261	24	223	0	0
F	262	251	269	304	32	230	0	0
G	396	392	393	396	177	220	0	0
H	266	231	274	322	0	325	0	0
I	146	141	144	149	26	120	0	0
J	248	247	251	258	6	242	0	0
K	163	153	159	164	76	87	0	0
L	182	182	184	187	17	165	0	0
Total	2711	2607	2724	2867	585	2185	0	0

- 90 – 100 km fits geological situation well,
- LHC suitable as potential injector

Key Technology R&D - HFM



Conductor R&D

Magnet Design

- Increase critical current density
- Obtain high quantities at required quality
- Material Processing
- Reduce cost

- Develop 16T short models
- Field quality and aperture
- Optimum coil geometry
- Manufacturing aspects
- Cost optimisation

FCC Magnet Technology Program

Main Milestones of the FCC Magnets Technologies

Milestone	Description	15	2016		2017		2018		2019		2020		21
M0	Supporting wound conductor program	■	■	■	■	■	■	■	■	■	■	■	■
M1	Design of an RMM with existing wire	■	■	■									
M2	Manufacture and test of a first 16T RMM			■	■	■							
M3	Procurement 35 km state of the art high J_c wire	■	■	■	■								
M4	Design of a 16T demonstrator with above wire			■	■	■							
M5	Manufacture and test of the 16T demonstrator					■	■	■					
M6	Procurement 70 km of enhanced high J_c wire				■	■	■	■	■				
M7	EuroCirCol design 16T accelerator quality model	■	■	■	■	■	■	■	■				
	Manufacture and test of the EuroCirCol model									■	■	■	■

FCC-hh: some design challenges

- **Stored beam energy: 8 GJ/beam (0.4 GJ LHC) = 16 GJ total**
  ➔ equivalent to an Airbus A380 (560 t) at full speed (850 km/h)

- ➢ **Collimation, beam loss control, radiation effects: very important**
- ➢ **Injection/dumping/beam transfer: very critical operations**
- ➢ **Magnet/machine protection: to be considered early on**

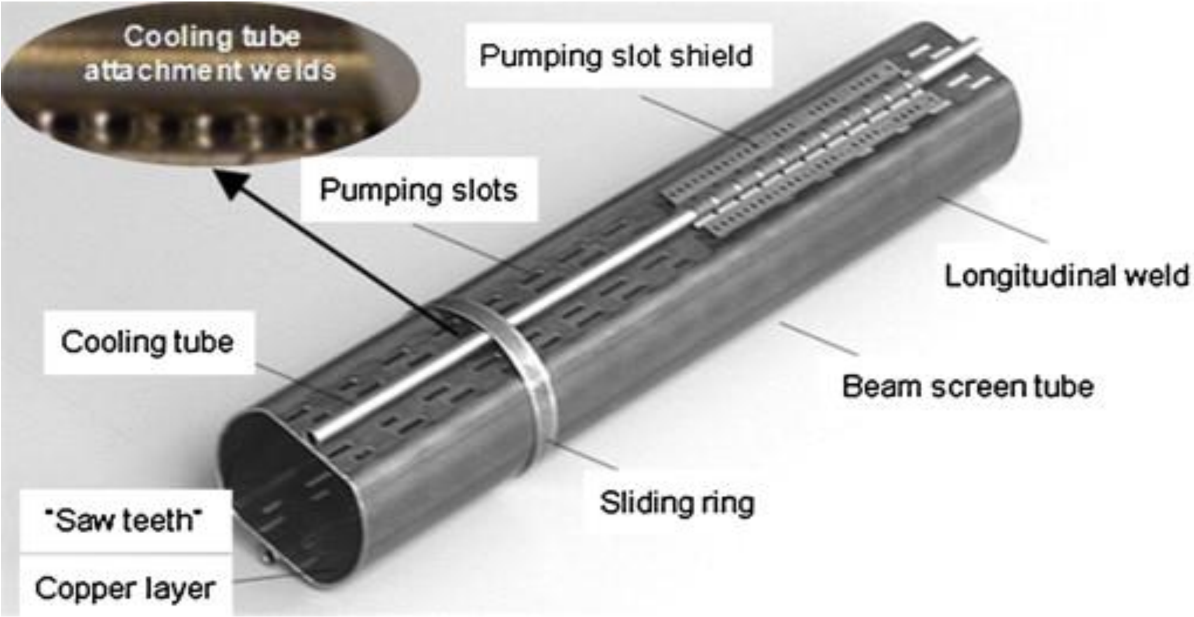
Synchrotron radiation/beam screen

High synchrotron radiation load (SR) of protons @ 50 TeV:

~30 W/m/beam (@16 T)

→ **5 MW total in arcs**

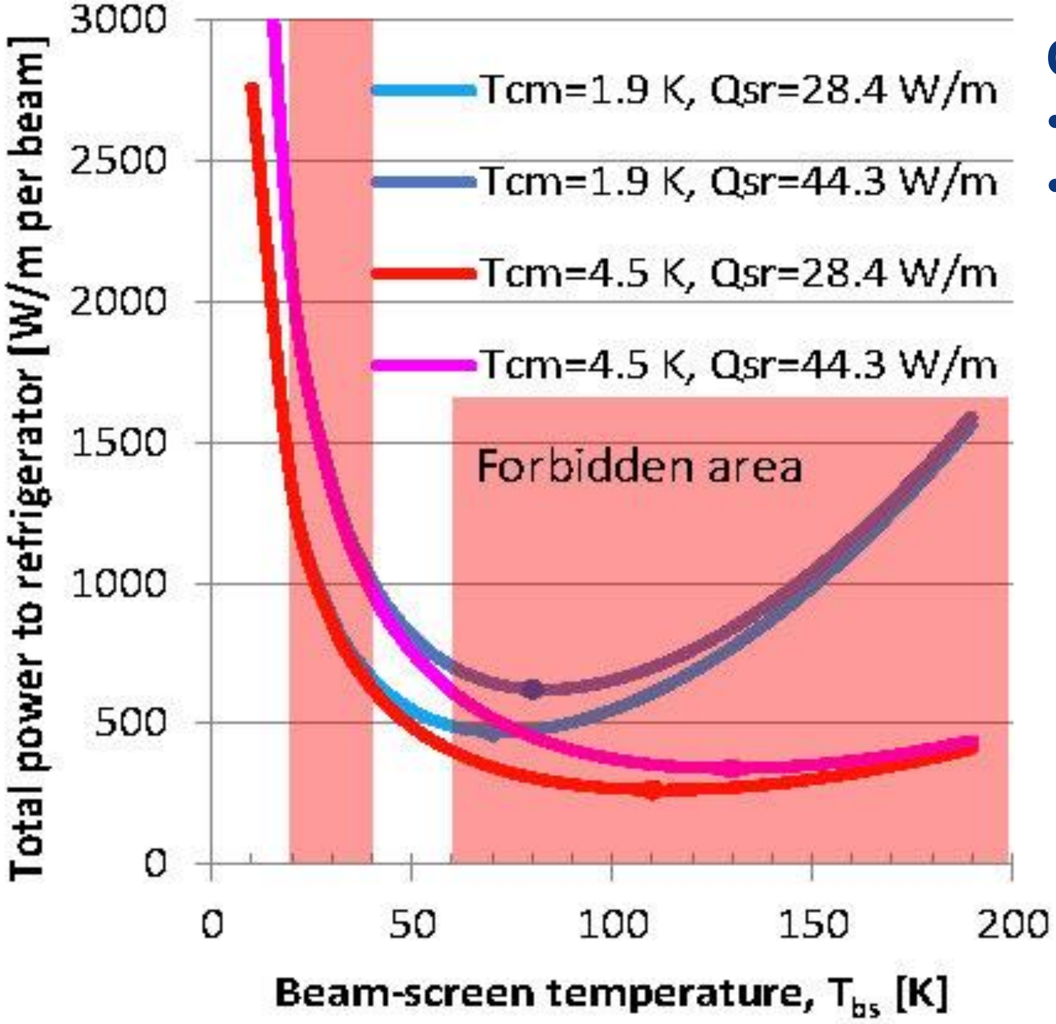
→ (LHC <0.2W/m)



- **Beam screen to capture SR and "protect" cold mass**
- **Power mostly cooled at beam screen temperature;**
- **Only minor part going to magnets at 2 – 4 K**

→ Optimisation of temperature, space, vacuum, impedance, e-cloud, etc.

Cryo power for cooling of SR heat



Contributions to cryo load:

- **beam screen (BS) &**
- **cold bore (BS heat radiation)**

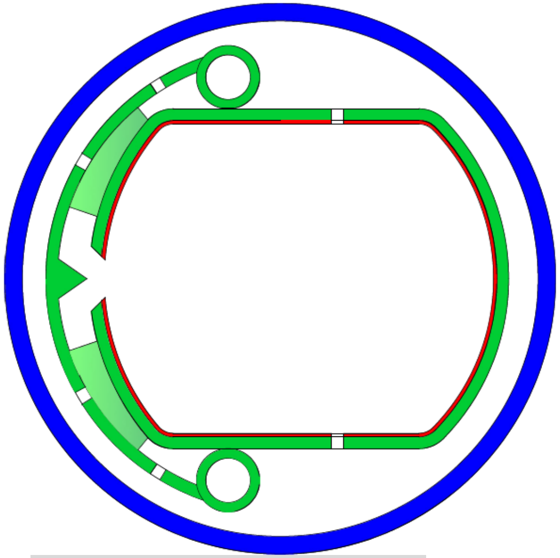
At 1.9 K cm optimum BS temperature range: 50-100 K; But impedance increases with temperature → instabilities

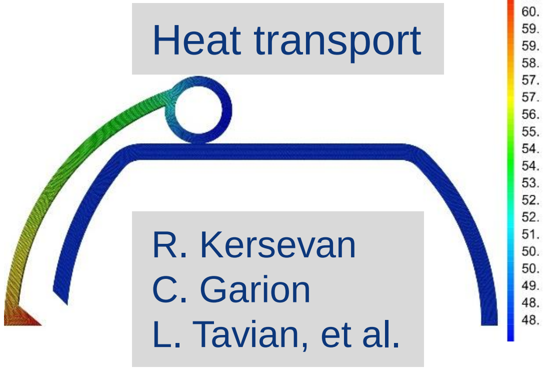
40-60 K favoured by vacuum & impedance considerations

→ 100 MW refrigerator power on cryo plant

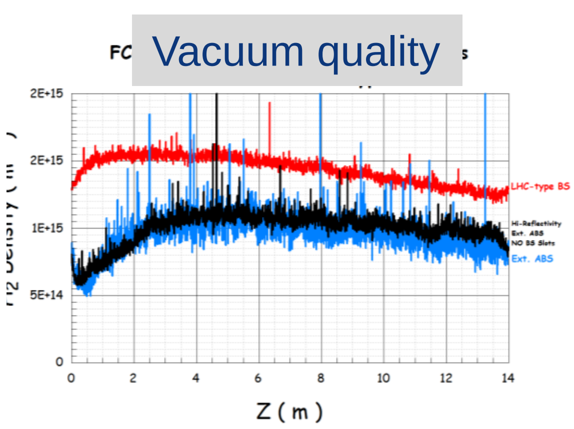
P. Lebrun, L. Tavian

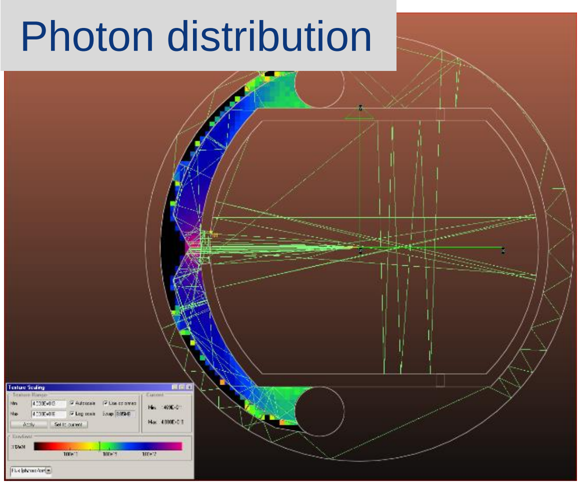
Beam screen design example




Heat transport

R. Kersevan
C. Garion
L. Tavian, et al.


Vacuum quality


Photon distribution

New type of ante-chamber

- Absorption of synchrotron radiation
- Avoid photo-electrons
- Help beam vacuum

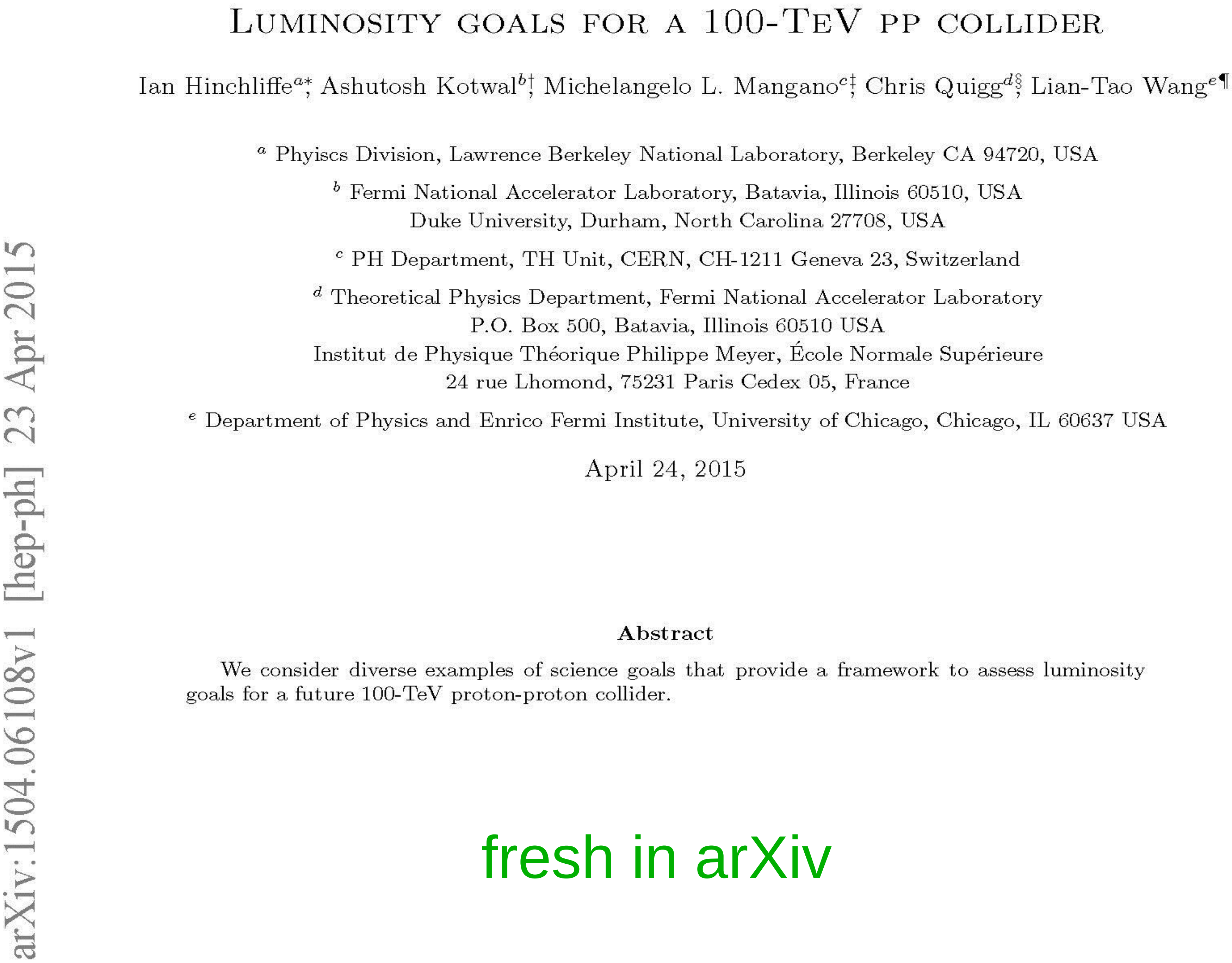
FCC-hh luminosity goals & phases

- **Two parameter sets for two operation phases:**

  - **Phase 1 (baseline): 5 x 10^{34} cm^{-2}s^{-1} (peak),**
    250 fb^{-1}/year (averaged)
    2500 fb^{-1} within 10 years (~HL LHC total luminosity)

  - **Phase 2 (ultimate): ~2.5 x 10^{35} cm^{-2}s^{-1} (peak),**
    1000 fb^{-1}/year (averaged)
    ➔ 15,000 fb^{-1} within 15 years

  - **Yielding total luminosity O(20,000) fb^{-1} over ~25 years of operation**



Luminosity goals for a 100-TeV pp collider

Ian Hinchliffe[a*], Ashutosh Kotwal[b†], Michelangelo L. Mangano[c‡], Chris Quigg[d§], Lian-Tao Wang[e¶]

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[b] Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
Duke University, Durham, North Carolina 27708, USA

[c] PH Department, TH Unit, CERN, CH-1211 Geneva 23, Switzerland

[d] Theoretical Physics Department, Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510 USA
Institut de Physique Théorique Philippe Meyer, École Normale Supérieure
24 rue Lhomond, 75231 Paris Cedex 05, France

[e] Department of Physics and Enrico Fermi Institute, University of Chicago, Chicago, IL 60637 USA

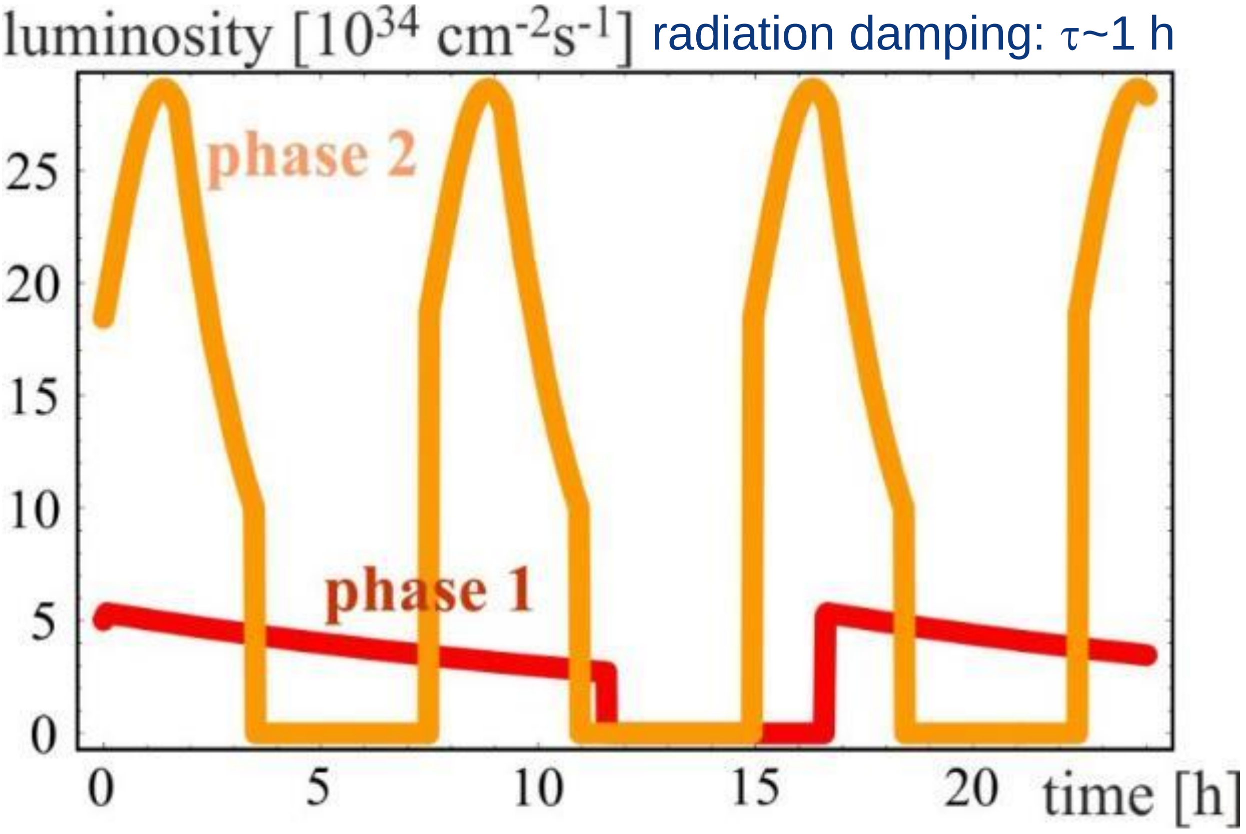
April 24, 2015

Abstract

We consider diverse examples of science goals that provide a framework to assess luminosity goals for a future 100-TeV proton-proton collider.

fresh in arXiv

luminosity evolution over 24 h



for both phases:

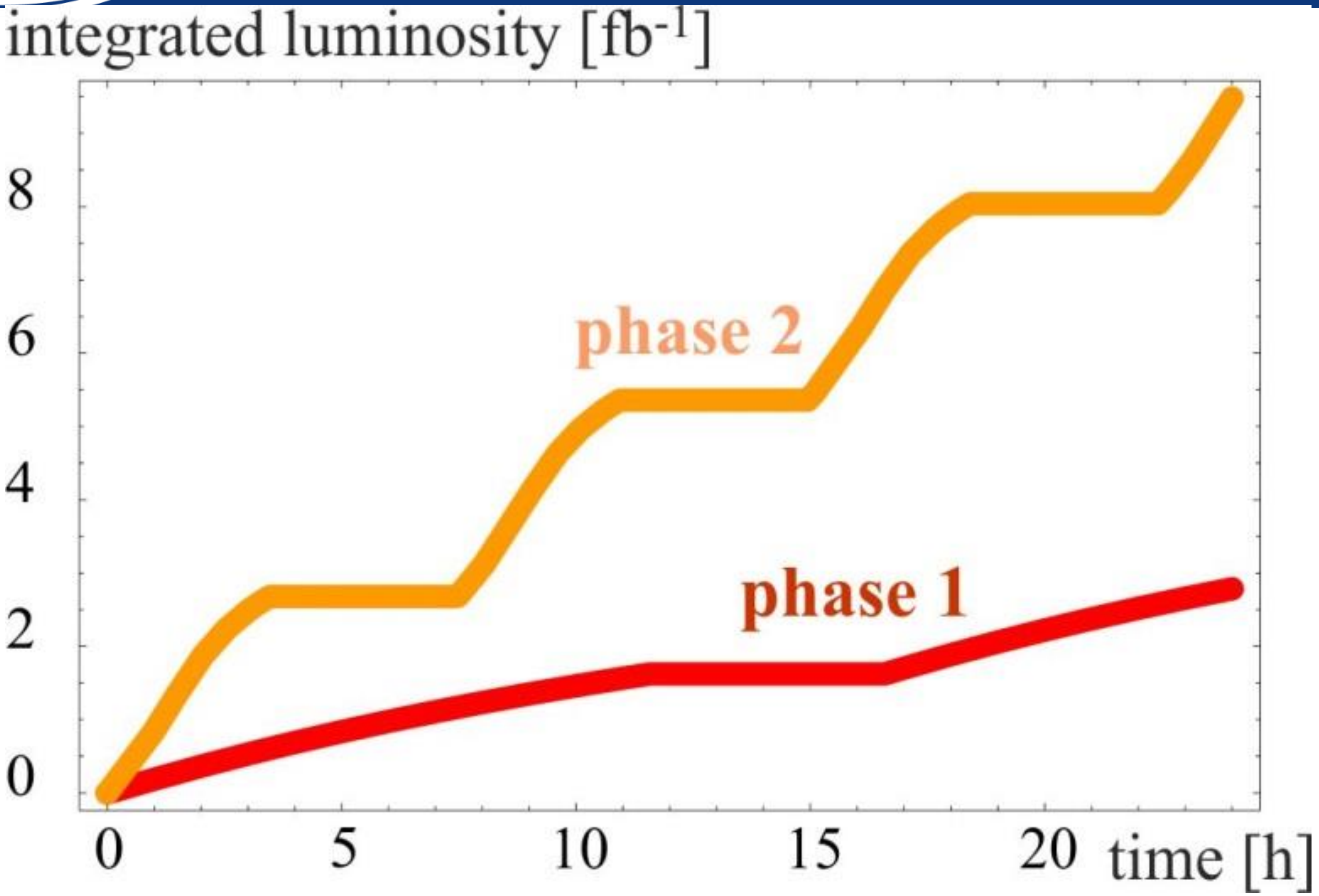
beam current 0.5 A unchanged!

total synchrotron radiation power ~5 MW.

phase 1: $\beta^*=1.1$ m, $\Delta Q_{tot}=0.01$, $t_{ta}=5$ h

phase 2: $\beta^*=0.3$ m, $\Delta Q_{tot}=0.03$, $t_{ta}=4$ h

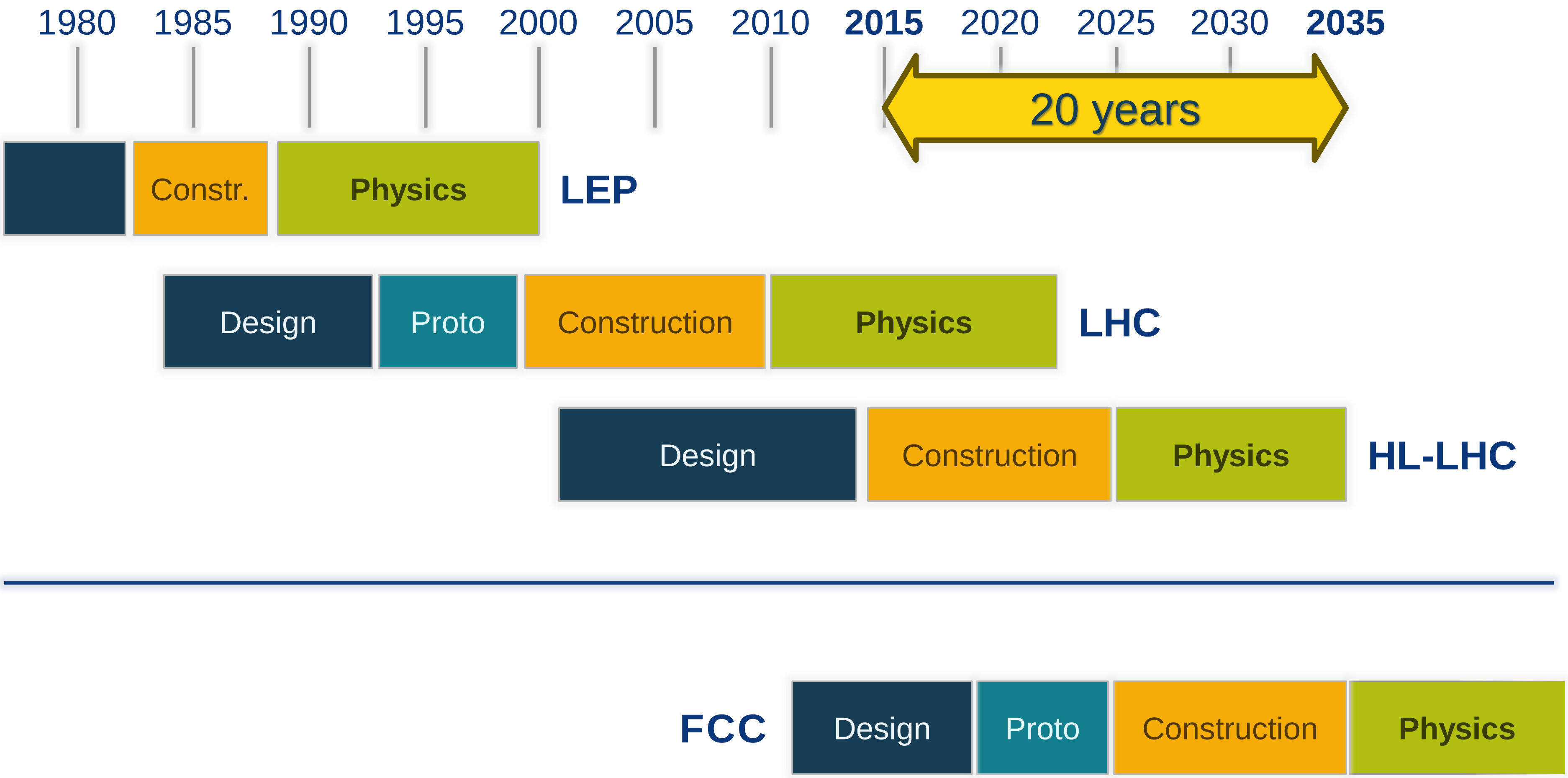
integrated luminosity / day



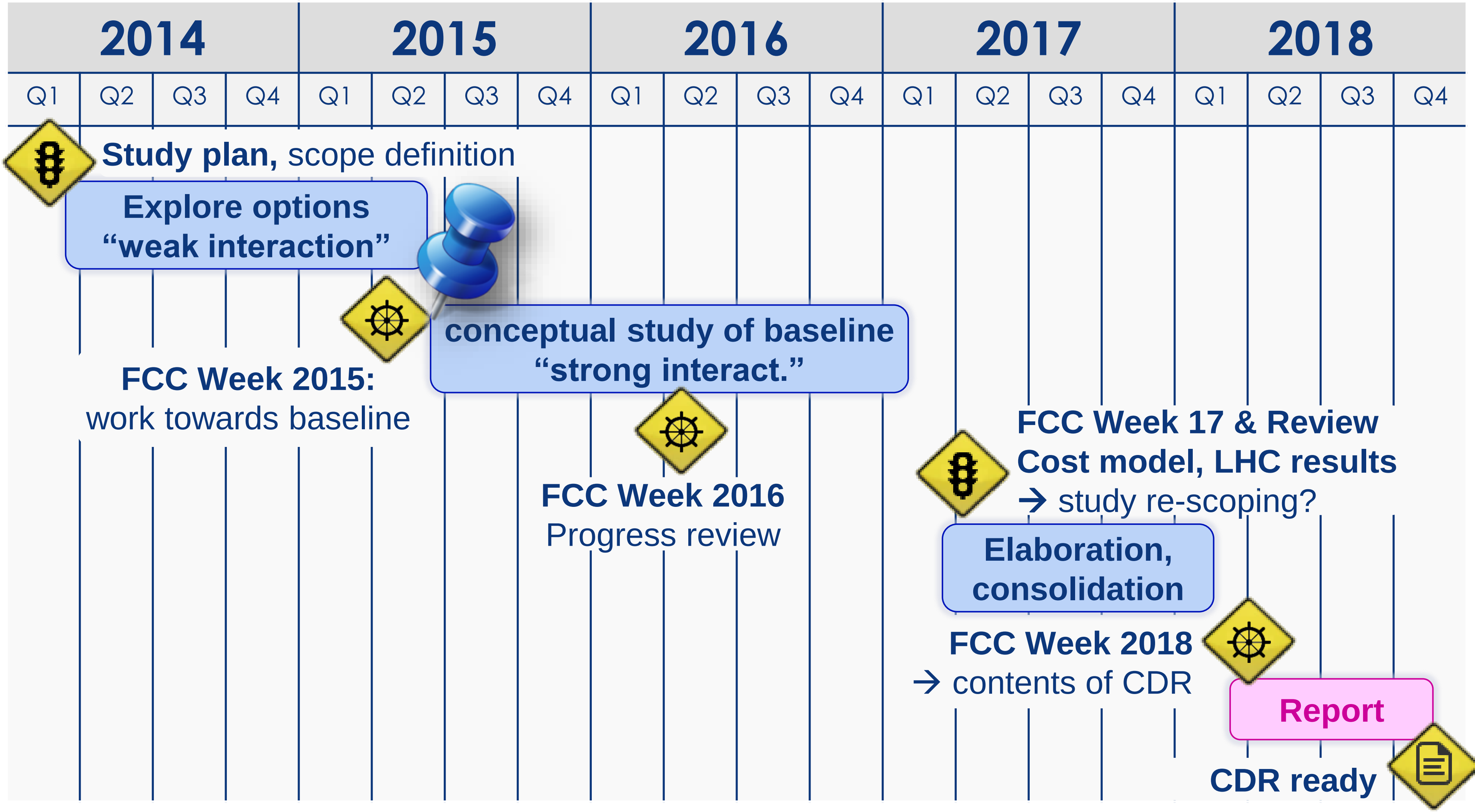
phase 1: β^*=1.1 m, ΔQ_{tot}=0.01, t_{ta}=5 h

phase 2: β^*=0.3 m, ΔQ_{tot}=0.03, t_{ta}=4 h

CERN Circular Colliders + FCC



Study time line towards CDR



Study plan, scope definition

Explore options “weak interaction”

FCC Week 2015: work towards baseline

conceptual study of baseline “strong interact.”

FCC Week 2016 Progress review

FCC Week 17 & Review Cost model, LHC results → study re-scoping?

Elaboration, consolidation

FCC Week 2018 → contents of CDR

Report

CDR ready

Collaboration Status

- 57 institutes
- 22 countries + EC

Status: July 30, 2015

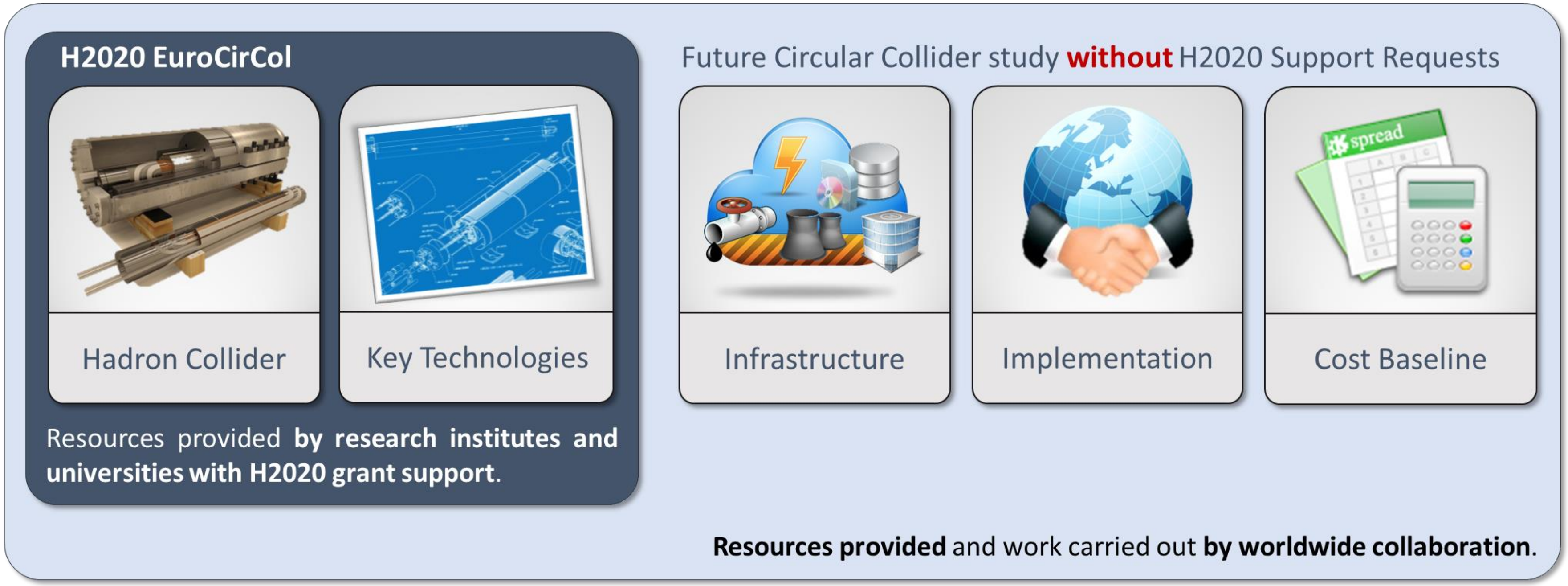
FCC Collaboration Status

57 collaboration members & CERN as host institute, 29 June 2015

ALBA/CELLS, Spain
Ankara U., Turkey
U Belgrade, Serbia
U Bern, Switzerland
BINP, Russia
CASE (SUNY/BNL), USA
CBPF, Brazil
CEA Grenoble, France
CEA Saclay, France
CIEMAT, Spain
CNRS, France
Cockcroft Institute, UK
U Colima, Mexico
CSIC/IFIC, Spain
TU Darmstadt, Germany
DESY, Germany
TU Dresden, Germany
Duke U, USA
EPFL, Switzerland
GWNU, Korea
U Geneva, Switzerland
Goethe U Frankfurt, Germany
GSI, Germany
Hellenic Open U, Greece
HEPHY, Austria
U Houston, USA
IFJ PAN Krakow, Poland
INFN, Italy
INP Minsk, Belarus
U Iowa, USA
IPM, Iran
UC Irvine, USA
Istanbul Aydin U., Turkey
JAI/Oxford, UK
JINR Dubna, Russia
FZ Jülich, Germany
KAIST, Korea
KEK, Japan
KIAS, Korea
King's College London, UK
KIT Karlsruhe, Germany
Korea U Sejong, Korea
MEPhI, Russia
MIT, USA
NBI, Denmark
Northern Illinois U., USA
NC PHEP Minsk, Belarus
U. Liverpool, UK
U Oxford, UK
PSI, Switzerland
Sapienza/Roma, Italy
UC Santa Barbara, USA
U Silesia, Poland
TU Tampere, Finland
TOBB, Turkey
U Twente, Netherlands
Wroclaw UT, Poland

EuroCirCol EU Horizon 2020 Grant

EC contributes with funding to FCC-hh study



H2020 EuroCirCol

Hadron Collider

Key Technologies

Resources provided **by research institutes and universities with H2020 grant support**.

Future Circular Collider study **without** H2020 Support Requests

Infrastructure

Implementation

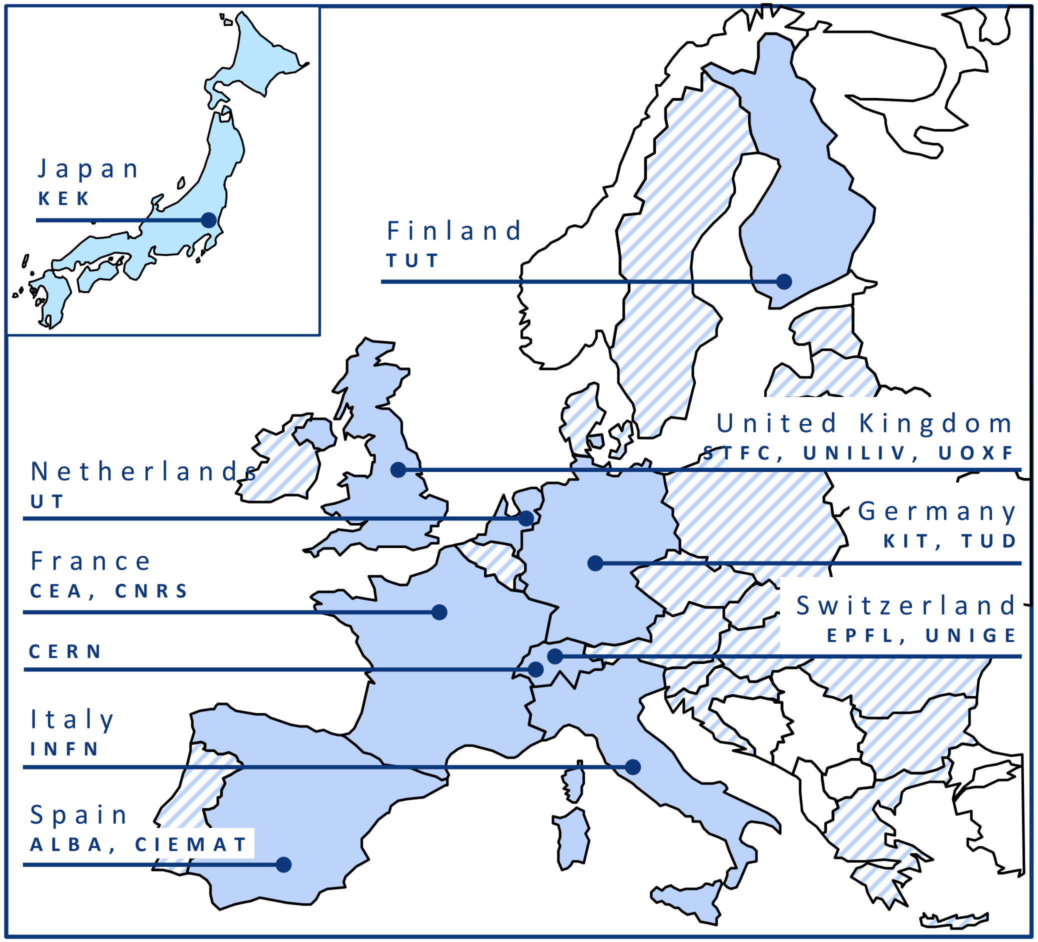
Cost Baseline

Resources provided and work carried out **by worldwide collaboration**.

- Core aspects of hadron collider design: arc & IR optics design, 16 T magnet program, cryogenic beam vacuum system
- **Recognition of FCC Study by European Commission**

EuroCirCol Consortium + Associates

CERN	IEIO
TUT	Finland
CEA	France
CNRS	France
KIT	Germany
TUD	Germany
INFN	Italy
UT	Netherlands
ALBA	Spain
CIEMAT	Spain
STFC	United Kingdom
UNILIV	United Kingdom
UOXF	United Kingdom
KEK	Japan
EPFL	Switzerland
UNIGE	Switzerland
NHFML-FSU	USA
BNL	USA
FNAL	USA
LBNL	USA



Consortium Beneficiaries, signing the Grant Agreement

Conclusions

- There are strongly rising activities in energy-frontier circular colliders worldwide.
- The FCC collaboration is hosted by CERN and will conduct an international study for the design of Future Circular Colliders (FCC).
- The design of high energy proton colliders presents many challenging R&D requirements in SC magnets, beam handling and several other technical areas.
- Global collaboration in physics, experiments and accelerators and the use of all synergies is essential to move forward.

FCC Week 2016

Rome, 11-15 April 2016